Appendix C
Drainage System Designs for U-frame and Trapezoidal Channels

B-1. Information Required for Seepage Analysis

a. Investigation. The scope of an investigation of subsurface soil/rock and ground water conditions for a channel project is normally influenced by the cost, complexity, and criticality of the project as well as requirements to protect adjacent development. Borings are required to determine the extent, thickness, and stratification of subsurface soils or rock along the channel project. Guidance on developing and conducting geotechnical investigations is presented in EM 1110-1-1804,* and guidance on soil sampling is presented in EM 1110-2-1907. The ground water levels along the project should be determined along with the variations in levels with the seasons of the year, rainfall, stream stage, etc. Ground water observations over an extended period of time are required to establish variations in ground water levels. General information regarding ground water levels is often available from public agencies. Specific information is best determined from long-term observations of piezometers. Piezometers to observe ground water fluctuations are not routinely installed for typical channel projects but should always be installed where drainage considerations are critical to channel performance. The use and installation of piezometers are described in EM 1110-2-1908 and TM 5-818-5.

b. Testing. The sizing of the drainage system is directly related to the amount of water entering the system which, in turn, is related to the permeabilities of the pervious strata within which the channel is constructed. The permeabilities of the pervious subsurface soils can be determined using laboratory and/or field permeability test methods. The simplest approximation method consists of visual examination and classification, and comparison with materials of known permeability. Empirical correlations are also available between grain size and permeability. Field methods include pumping tests and constant or falling head tests made in piezometers or open boreholes. EM 1110-2-1901 and TM 5-818-5 provide recommendations and procedures for determining permeability.

c. Design requirements. The drainage system should be designed for the ground water level/stream stage which yields the critical differential head. This requires an evaluation of the variations in ground water levels coincident with variations in stream stage.

B-2. Design Example for U-Frame Channel Drainage System

a. General. Since drainage blankets are thin compared to the overall dimensions of a channel and surrounding soils, it is difficult to produce an accurate flow net within the boundaries of the drainage blankets. As stated in EM 1110-2-1901 (page 8-11), the total quantity of seepage from all sources that must discharge through drains should be evaluated from a flow net analysis in which it is assumed that the drains have an infinite permeability. To evaluate the quantity of seepage into drainage blankets for an assumed U-frame flood control channel with the foundation soil conditions shown in Figure C-1, the computer program SEEP2D (Knowles 1992, Tracy 1983, Biedenharn and Tracy 1987 (Seepage Package (x8202)) was used. The sequence of silty sand and fine sand in Figure C-1 is for alluvial conditions where permeability increases with depth. To compute seepage quantity, it was necessary to consider only the foundation soils beneath the assumed high ground water level to obtain the quantities of seepage that would flow into an inclined drainage blanket behind the wall and into a horizontal drainage blanket beneath the concrete lined channel.

b. Distance to effective source. The distance to the source of steady state seepage from the U-frame wall was taken as the radius of influence *R* for the silty sands and was estimated from TM 5-818-5, Figure 4-23 as

$$R = C(H - h_w)(k)^{1/2} \qquad \text{(C-1)}$$

where

C = 3 for artesian and gravity flows

H = total head in feet

hw = tailwater head in feet

k = coefficient of permeability expressed in 10^{-4} cm/sec

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* References in Appendices C and D are listed in Appendix A.

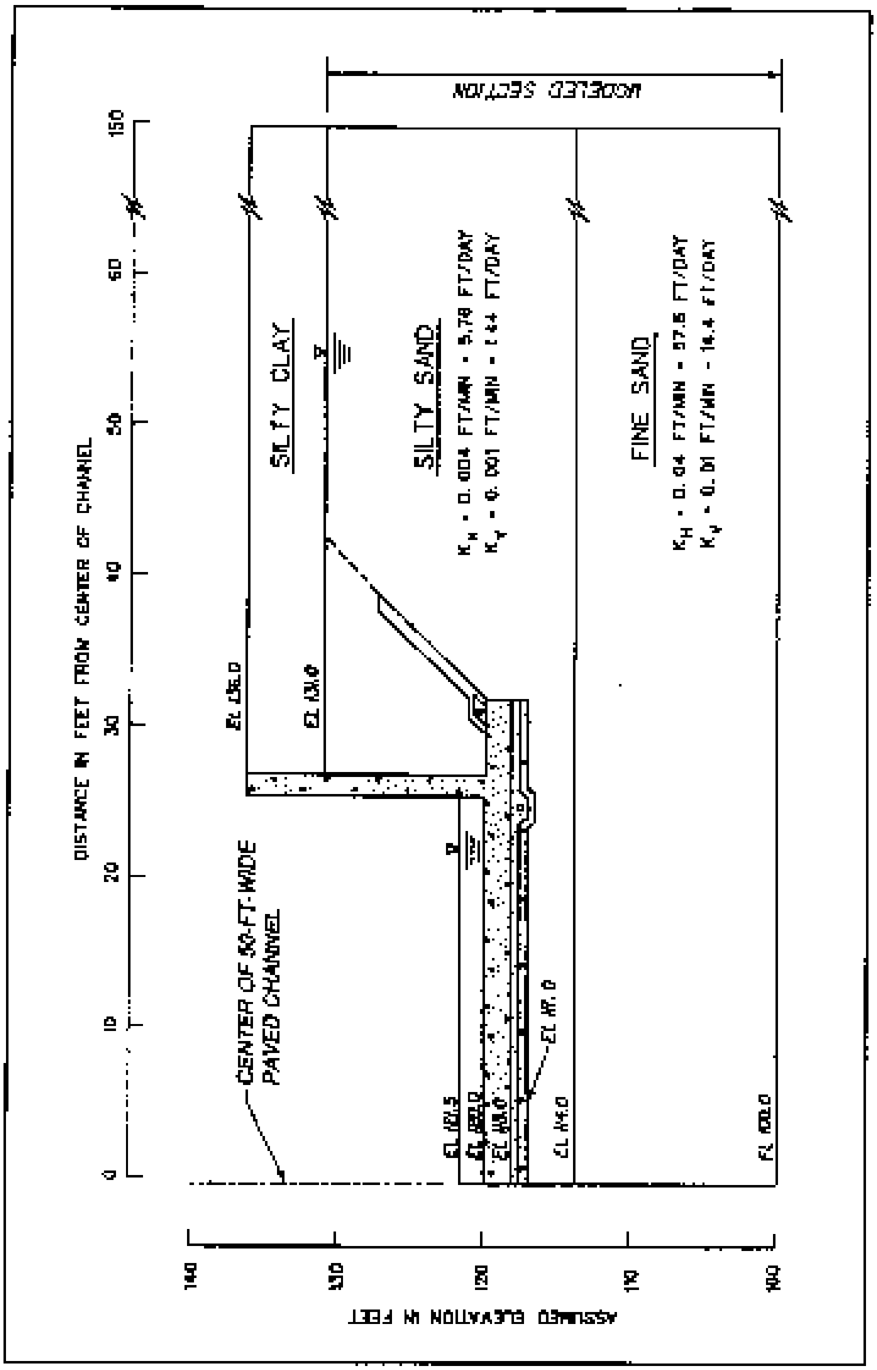

Figure C-1. Example U-frame channel and foundation conditions

The distance of half the channel width was added to *R* to obtain the x-coordinate. Using a value of *H* of 31 ft, *hw* of 21.5 ft, and *k* of 20 (without the 10-4 cm/sec), *R* was computed as 127 ft and the value of *x* (*R* + half the channel width) was equal to 152 which was rounded down to 150 ft. The section used for the seepage analyses with the CSEEP program package is shown in Figure C-2.

c. Seepage computer program. The seepage program package, SEEP2D, was used because it includes (1) a preprocessor program for quick definition of the problem and automatic generation of the nodes and elements; (2) a solution program for steady-state, two-dimensional seepage that automatically converges and produces a data file that includes a list of nodal points and their coordinates, elements, flows, and heads at nodal points, total inflow and total outflow, and flows and velocities for elements; and (3) a post processor program with options to produce plots of flow nets, vector diagrams, number diagrams of head or percent head, contours (equipotential lines), displaced outline, orthographic grid, or perspective grid. A graphical flow net can be obtained for problems limited to two soil types, although a listing of flows and heads can be obtained for up to 12 different soil types.

(1) Preprocessor program. The preprocessor program (X8200) requires two data files. One file is for input of boundary point coordinates, fixed or moveable points, number and spacing of intermediate node points, and material type. The other is for definition of boundary conditions with regard to head or flow, entrance or exit boundaries, and no flow boundaries. The data files for the U-frame channel example are listed in Table C-1. The preprocessor program requests an input data file name and a restart file name, then the boundary data file name and a name for the data file to be generated for use with the solution program. After module 4 is reached and PLT is entered, followed by T for total, the grid is drawn on the screen. The screen image can be saved to a file generated by the program to be printer plotted later using a program named EPRINT. The resulting grid for the example problem is shown in Figure C-3. Several trials may be needed to obtain a desirable grid.

(2) Solution program. The solution program (X8202) operates by asking for the file name from the preprocessor program and then other questions, the last of which requests names for the solution data file and file for plotting with the post processor program. In this example, a normal solution with a smooth phreatic surface and the flow net option was obtained after six iterations.

(3) Postprocessor program. The post processor program (X8201) can be used to obtain plots with axes, bigger plots, selected windows, and other types of plots. Results of the analysis are shown by a flow net in Figure C-4, a vector diagram in Figure C-5, and an elevation head plot in Figure C-6. The vector plot indicates that most of the flow will go into the base drainage blanket from the lower more permeable fine sand layer. As shown in Figure C-6, the elevation heads along the exit surface to the drainage blankets are at the tailwater elevation head of 121.5 ft except at the intersection of the phreatic surface with the inclined collector where the head is at elevation 122.01 ft.

(4) Exit flows. An extracted listing of the seepage data results from the solution program is shown in Table C-2. The first section of the table lists the node numbers and their coordinates along the exit drainage boundary, and the next section lists the node numbers, heads, percent head, outflow quantities (negative numbers), and location of the node with respect to the phreatic surface with the total inflow and total outflow listed and compared at the end. A list of the elements, element flow velocities, and vectors produced by the solution program was deleted from the data shown in Table C-2. The flows at the nodes are those for the proportional width along the boundary and correspond to the width of boundary elements. The flows are in the same kind of units used for the entered permeabilities, i.e. flows are in cubic feet per day in this example.

d. Design of drainage system. The drainage system will consist of a drainage blanket, collector drains, collector manholes, and outlet drains. The drainage blanket will consist of either one or two layers depending on whether or not one gradation of material will satisfy both the filter and drainage requirements. One collector drain will be placed behind the wall and three drains will be placed in the blanket beneath the channel bottom. One of the collector drains will be placed in the center where uplift will be most critical, and one drain will be placed along each side. Lateral drains will connect the collector drains to manholes located behind the walls. Outlet drains will discharge from the manholes into the channel.

(1) Drainage blanket. The flows into the drainage blanket from the seepage analysis are shown in Figure C-7. Total flow into the inclined drainage blanket is 6.0 cu ft/day and 43.6 cu ft/day into the base drainage blanket. These are flow rates per running foot of channel. Flow into the base drainage blanket can be divided into 16.3 cu ft/day into the center drain pipe and

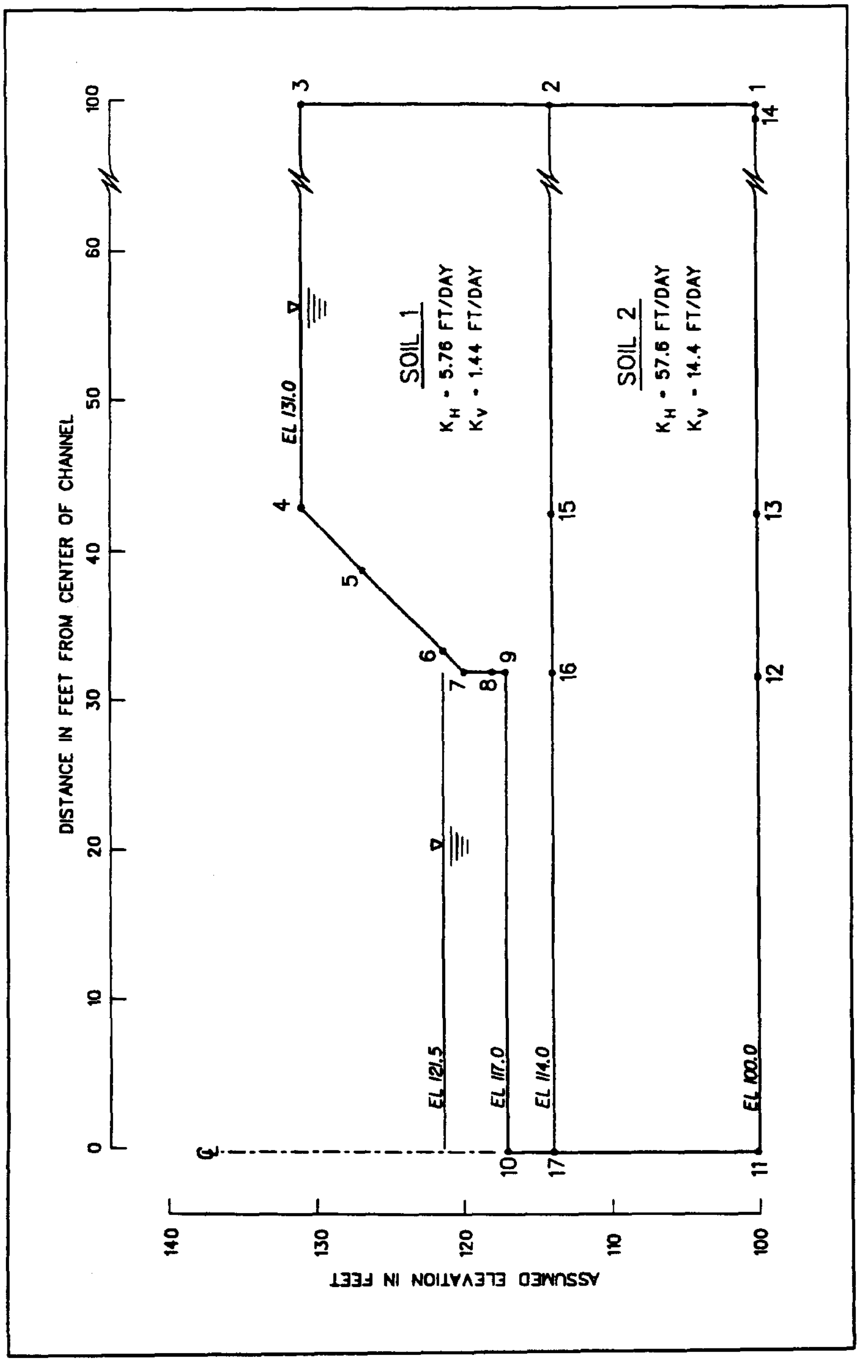

Figure C-2. Profile utilized in developing data file

Table C-1
Data Files for U-frame Channel Seepage Analysis

File UCHLLSI

100	1	150	100			
110	2	150	114			
120	3	150	131			
130	4	43	131			
140	5	39	127			
150	6	33.5	121.5			
160	7	32	120			
170	8	32	118			
180	9	32	117			
220	10	0	117			
230	11	0	100			
240	12	32	100			
250	13	43	100			
255	14	142	100			
260	15	43	114			
265	16	32	114			
270	17	0	114			
275	-1					
280	1	2	F	L	4	2
285	2	3	F	L	6	1
290	2	15	F	L	8	2
295	3	4	F	L	8	1
300	4	5	F	L	1	1
310	5	6	F	L	2	1
320	6	7	F	L	0	1
330	7	8	F	L	0	1
335	8	9	F	L	0	1
340	11	17	F	L	4	100
350	17	10	F	L	0	100
360	10	9	F	L	6	100
370	11	12	F	L	6	2
375	12	16	F	L	4	2
380	12	13	F	L	4	2
390	13	15	F	L	4	2
400	13	14	F	L	7	2
410	14	1	F	L	0	2
420	15	4	F	L	6	1
450	15	16	F	L	4	2
455	17	17	F	L	6	2
460	9	9	F	L	0	1

File UCHLLB

100	P	1	1	1	131.0
110	P	2	1	1	131.0
120	P	3	0	1	131.0
130	A	1	1	0	
140	P	4	1	2	121.5
150	P	5	1	2	121.5
160	P	6	0	2	121.5
170	P	7	1	1	121.5
180	P	8	1	1	121.5
190	P	9	1	1	121.5
200	P	10	0	1	121.5
210	P	17	1	0	
220	P	11	1	0	
230	P	12	1	0	
240	P	13	1	0	
250	P	15	1	0	
260	P	16	1	0	
270	P	14	0	0	

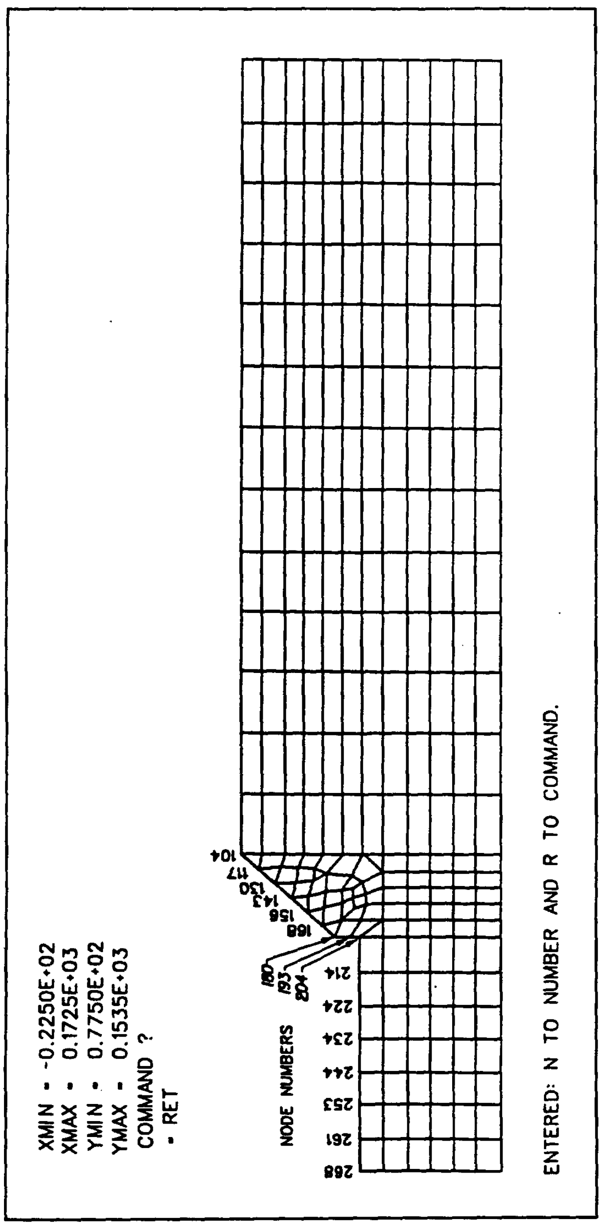

Figure C-3. *Finite element grid used for analysis of U-frame channel section*

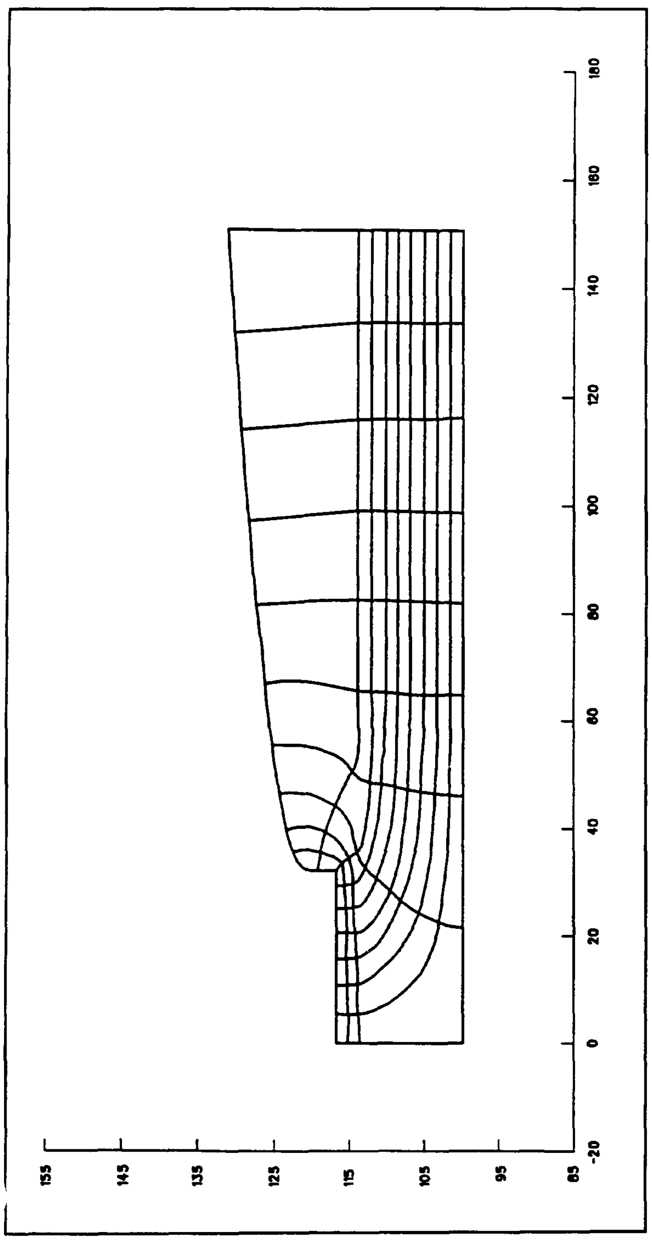

Figure C-4. Flow net from analysis of U-frame channel section

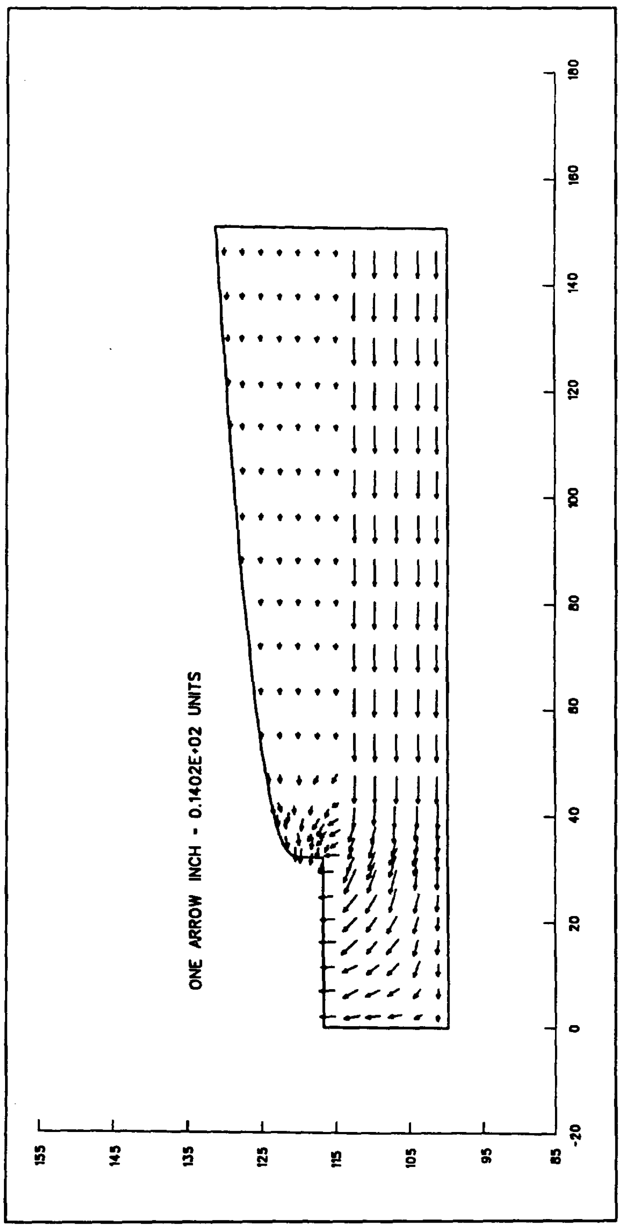

Figure C-5. Vector diagram of flow from analysis of U-frame channel section

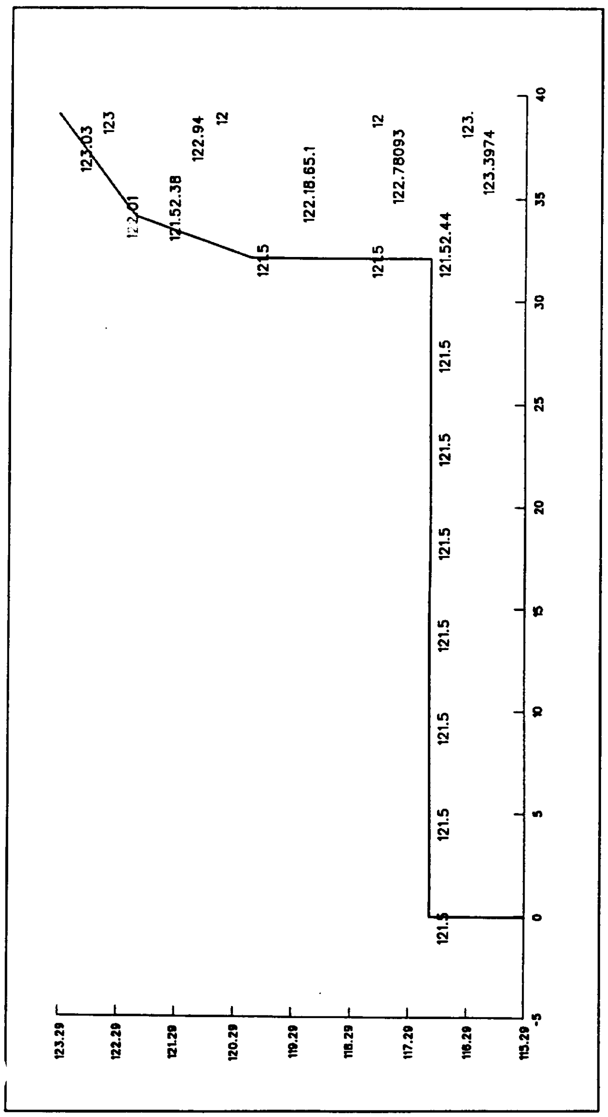

Figure C-6. Elevation head plot from analysis of U-frame channel section

Table C-2
Results of Seepage Analysis for U-Frame Channel (Continued)

Plane Flow Problem

U-Channel Underdrain with Inclined Wall Drain

0 Number of Nodal Points-----------289
0 Number of Elements----------------257
0 Number of Diff. Materials---------2
0 Elevation of Datum-----------------0.000

Material Properties

MAT	K1	K2
1	0.576E+01	0.144E+01
2	0.576E+02	0.144E+02

Node Point Information

Node	BC	X	Y	Flow-Head
		Sections of Listing Omitted		
104	2	43.00	131.00	121.50
117	2	41.00	129.00	121.50
130	2	39.00	127.00	121.50
143	2	37.17	125.17	121.50
156	2	35.33	123.33	121.50
168	2	33.50	121.50	121.50
180	1	32.00	120.00	121.50
193	1	32.00	118.00	121.50
204	1	32.00	117.00	121.50
214	1	27.43	117.00	121.50
224	1	22.86	117.00	121.50
234	1	18.29	117.00	121.50
244	1	13.71	117.00	121.50
253	1	9.14	117.00	121.50
261	1	4.57	117.00	121.50
268	1	0.00	117.00	121.50

Nodal Flows and Heads

Node	Head	Percentage of Available Head		Flow
Position of Phreatic Surface				
Above / On	Below	X	Y	
		Parts of Listing Omitted		
141		0.1237E+03	23.1%	
*		41.03	123.69	
142		0.1234E+03	20.4%	
*		39.40	123.44	
155		0.1230E+03	16.1%	
*		37.52	123.03	
156		0.1220E+03	5.4	
*		34.01	122.01	

Table C-2 (Concluded)

Nodal Flows and Heads
(Continued)

Node		Head	Percentage of Available Head		Flow
Position of Phreatic Surface					
Above	On	Below	X	Y	
168			0.1215E+03	0.0%	-0.3816E+01
180			0.1215E+03	0.0%	-0.2220E+01
193			0.1215E+03	0.0%	-0.2731E+01
204			0.1215E+03	0.0%	-0.8623E+01
214			0.1215E+03	0.0%	-0.05624E+01
224			0.1215E+03	0.0%	-0.5260E+01
234			0.1215E+03	0.0%	-0.4996E+01
244			0.1215E+03	0.0%	-0.04803E+01
253			0.1215E+03	0.0%	-0.4669E+01
261			0.1215E+03	0.0%	-0.4591E+01
268			0.1215E+03	0.0%	-0.2282E+01
		Flow(-) =	4.9615E+01	Flow (+) =	4.9619E+01
			Flow (Ave) =	4.9617E+01	

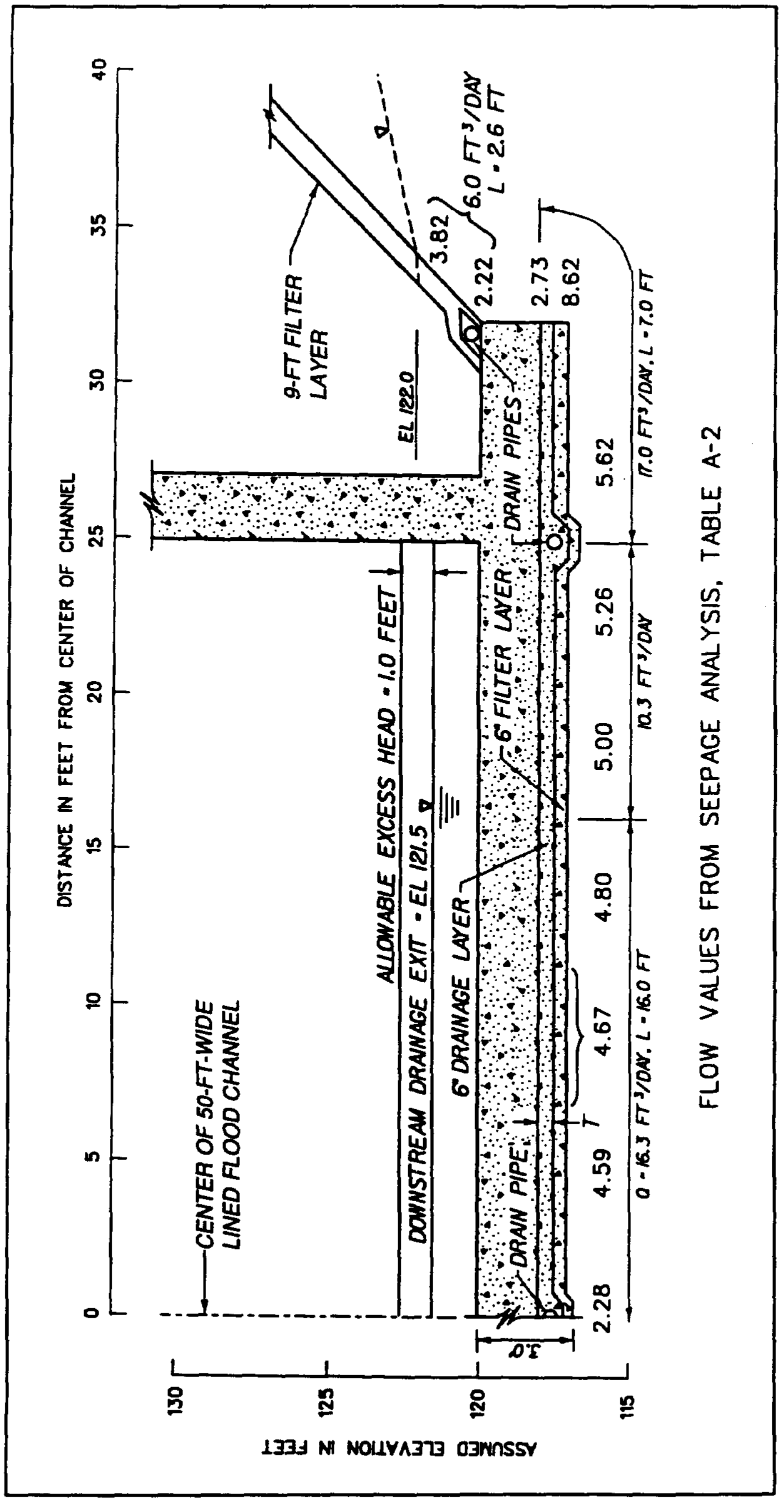

Figure C-7. Flows into drainage blanket from analysis of U-frame channel section

27.3 cu ft/day into the end drain pipes. Based on the distribution of flow to the drain pipes, the inclined drainage blanket should be designed to handle a minimum of 6.0 cu ft/day over a length of 2.6 ft and the base drainage blanket should be designed to handle a minimum of 16.3 cu ft/day into the center drain over a length of 16.0 ft. The gradation of the drainage blanket must meet the filter requirements for the natural silty sand foundation soils and also the drainage requirements. The gradation of the natural soils is represented by the grain size curve presented in Figure C-8. For this example, the gradation required to satisfy the filter criteria will be determined, and then computations will be performed to determine if the filter materials have adequate drainage capacity. If not, a two-layer drainage blanket will be required.

(a) Filter criteria. Filter criteria are presented in EM 1110-2-1901 and EM 1110-2-2502. Applying the stability and relative permeability criteria to the grain size curve for the natural foundation soils, the filter material gradations presented in Figure C-8 are obtained.

(b) Design procedure. The drainage blanket must have sufficient capacity to remove the seepage quickly without allowing high seepage pressures to develop. The variables in the blanket analysis consist of the thickness and permeability of the layer, and the permeability is in turn related to the gradations of the material. The analysis is based on Darcy's law:

$$k = \frac{Q}{iA} \tag{C-2}$$

where

k = permeability of drainage blanket

i = gradient (excess head divided by length of flow path)

A = area of blanket (thickness of blanket × 1.0 ft of channel width)

For design, the estimated permeability of the trial drain material is multiplied by a factor of 20 (EM 1110-2-2502) to provide a reserve and account for errors in the estimated versus the actual in-place permeabilities of sands and gravels used in drainage blankets. Since the drainage blanket is horizontal, some excess differential head is required in the blanket to cause flow to the collector drain. For purposes of the analysis, it is considered that a maximum excess differential head of 1.0 ft would be allowed.

(c) Blanket thickness. The thickness of the blanket can be determined from Equation C-2, for Darcy's law, assuming the excess head of 1.0 ft so that $i = 1/L$, where L is the path length and A, the area, is the thickness t_b × 1.0 for the unit length of the channel. Since

$$k_{b_{design}} = \frac{Q}{(1/L) \times t_b} \times 20 \tag{C-3}$$

then

$$tb = \frac{Q \times L \times 20}{k_{b_{design}}} \tag{C-4}$$

(d) Base drainage blanket. The first trial considers using the filter material to satisfy also the drainage requirements. The filter materials are estimated to have a permeability of 1.0 ft/min (TM 5-818-5, Table 3-4) or 1,440 ft/day. The blanket thickness for a permeability of 1,440 ft/day, a Q of 16.3 cu ft/day and a drainage-path length of 16 ft is equal to

$$t_b = \frac{16.3 \times 16 \times 20}{1{,}440} = \frac{5{,}216}{1{,}440} = 3.62 \text{ ft or } 43.5 \text{ in.}$$

Obviously, this thickness is not feasible and a two-layer drainage blanket will be required. A 3/8 in. to No. 4 sieve gravel has an estimated permeability of 8,000 ft/day (Cedegren 1989, Table 2.1). The thickness required for this permeability is

$$t_b = \frac{5{,}216}{8{,}000} \; 0.652 \text{ ft or } 7.8 \text{ in.}$$

which is rounded to 9 in. for a design thickness. For this thickness the design permeability would be

$$k_{b_{design}} = \frac{16.3 \times 16 \times 20}{9/12} = 6{,}955 \text{ ft/day}$$

The permeability value of 6,955 ft/day is rounded to 7,000 ft/day. To check for decrease in permeability caused by turbulence, the value of i (1/16 = 0.0625) and the effective size (0.3 in.) are used with Figure 6-9 from EM 1110-2-2502 to obtain a reduction factor. In this case, the factor is equal to 0.8 and the reduced

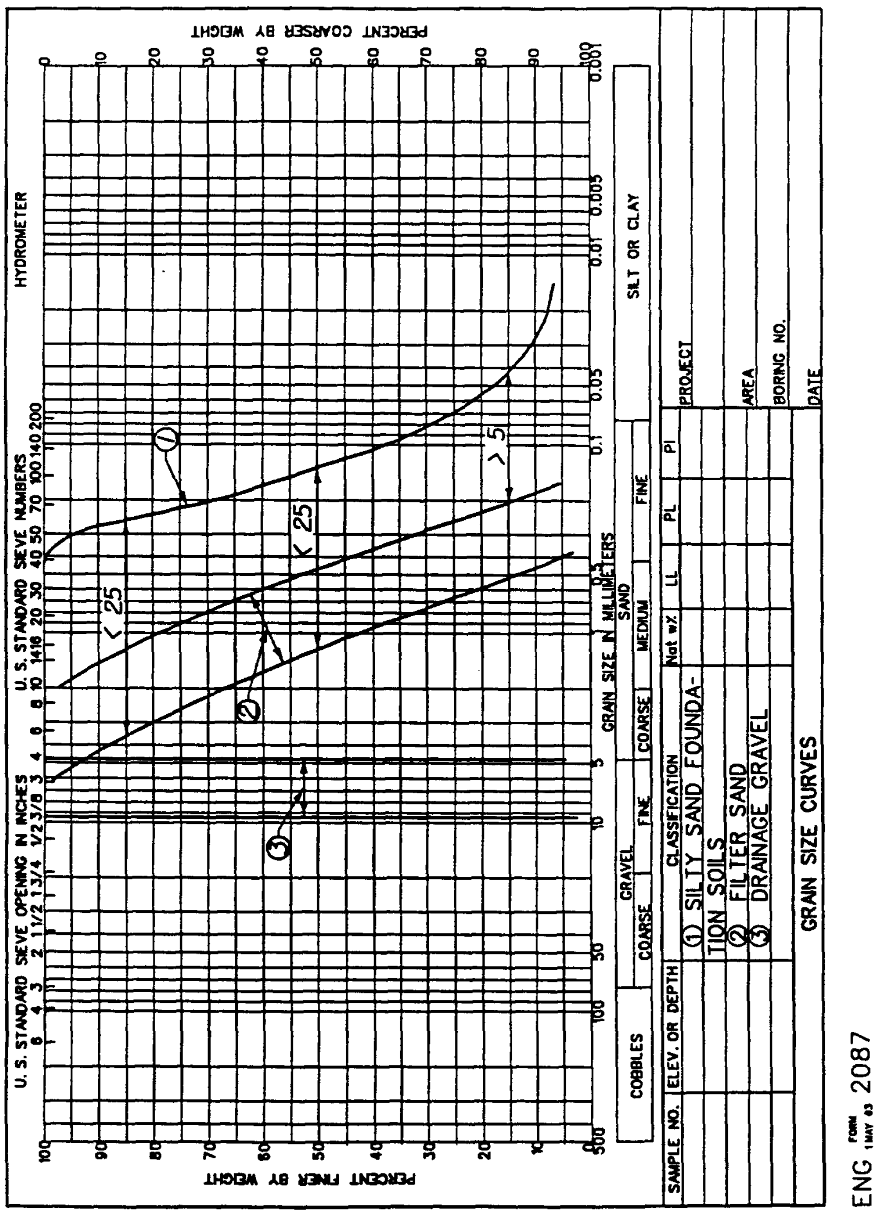

Figure C-8. Gradation of drainage materials for U-frame channel section permeability is 0.88 × 8,000 or 7,040 ft/day which is greater than the design value of 7,000 ft/day. Therefore, a two-layer drainage blanket consisting of 6 in. of filter sand and 9 in. of 3/8 in. to No. 4 sieve gravel should be used.

(e) Collector pipe. The center collector pipe will have a flow of 32.6 cu ft/day per linear foot of pipe (2 × 16.3 cu ft/day). Assuming manholes located behind the walls at 250-ft intervals, the accumulated discharge of the pipe will be 8,150 cu ft/day (250 ft × 32.6 cu ft/day/ft). The pipe size is estimated from the airfield drainage nomograph presented in Figure C-9 which requires flow in cubic feet per second and slope of the pipe. A flow of 8,150 cu ft/day is equal to 0.09 cu ft/sec. Considering a small slope of s = 0.0008 or 0.08 ft/100 ft, a 5-in.-diam pipe could be used. However, the minimum allowed is 6-in. diam. The opening sizes in the collector pipe should be determined using the following criteria.

Circular openings:

$$\frac{D_{50_F}}{Hole\ Diameter} > 1.0 \tag{C-5}$$

Slotted Openings:

$$\frac{D_{50_F}}{Hole\ Diameter} > 1.2 \tag{C-6}$$

Place 6-in. minimum thickness gravel layer around collector pipes. Use gravel having a 50 percent size of 3/8 in. and use 3/8-in. circular openings in collector pipe.

(3) Inclined drainage blanket. An excess head of 0.5 ft occurs at the inclined drain and the design k value for a filter blanket thickness of 9.0 in. is:

$$k_{b_{design}} = \frac{6.0 \times 2.6 \times 20}{0.5 \times 0.75} = 832 \text{ ft/day}$$

The filter material to be used below the base has an estimated permeability of 1,440 ft/day and should satisfy both the filter and drainage requirements for the inclined blanket. For this low Q and k, the minimum required collector pipe diameter size of 6 in. would be more than adequate.

(4) Manholes. Manholes behind the U-frame wall would be needed at 250-ft intervals. Outlet drains through the wall should be provided with check valves to prevent backflow into the drainage system.

3. Design Example for Trapezoidal Channel Drainage System

a. General. The trapezoidal channel example section is shown in Figure C-10. This example depicts deep alluvial fine sands that could produce large drainage quantities. A 100-ft-wide channel with a 2-ft-thick concrete lining was assumed. The distance to the steady state seepage source was estimated to be 625 ft from the center of the channel using the radius of influence Equation, C-1, described earlier. The head at the source was assumed to be at elevation 115 ft, and the head for drainage of the collector pipes into manholes was assumed to be at elevation 101.5 ft at the channel. The permeability of the sand was assumed to be 20 × 10^{-4} or 57.6 ft/day with a 4:1 ratio of horizontal to vertical permeability.

b. Seepage analyses. The SEEP2D program was used to determine the flow exiting from the silty sand foundation into the drainage and/or filter layer(s). The analysis was performed in the same manner as described for the U-frame channel in the previous example. The data files are listed in Table C-3 and an abbreviated listing of the tabular results from the analysis is shown in Table C-4.

Q	L	$Q \times L$
20.8	29	603
17	21	357
36.9	12	443

$$>>>> \quad t_b = \frac{20.8 \times 29 \times 20}{576}$$

$$t_b = 20.9 \text{ ft}$$

c. Design of drainage system. The flows out of the foundation that would enter the drainage and/or filter layer(s) are shown in Figure C-11. Collector pipes are assumed to be located at the center and on each side of the channel in the drainage blanket. The flow is divided into segments for each collector pipe as shown in Figure C-11, and the design permeability is determined for the largest $Q \times L$ combination using Equation C-3. The calculations shown below indicate that an open graded gravel drainage layer and filter layer would be required.

(1) Drainage blanket. Using Q and L from the largest $Q \times L$ value and an excess head of 1.0 ft, the drainage

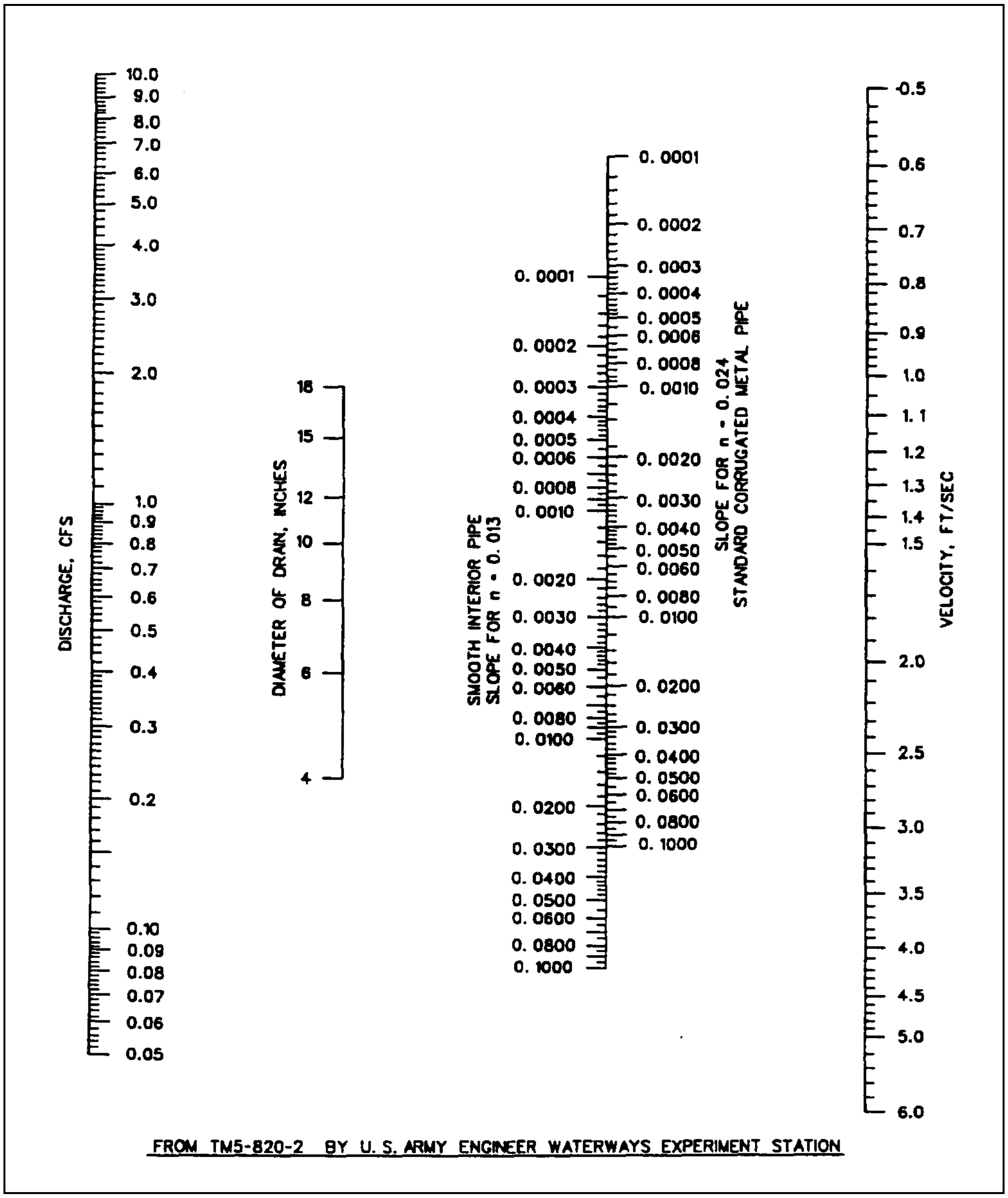

Figure C-9. Airfield drainage nomograph for computing required size of circular drain, flowing full

blanket thickness was determined for the coarse to medium filter sand shown in Figure C-10. The permeability of the filter sand is assumed to be 0.40 ft/min (TM 5-818-5, Table 3-4) or 576 ft/day. Using Equation C-4:

The thickness of 20.9 ft is unreasonable and a drainage layer and filter layer are needed. The design permeability from Equation C-3 is:

$$k_{b_{design}} = \frac{20.8 \times 29 \times 20}{0.5} = 24,128 \text{ ft/day}$$

Adequate drainage could be obtained using 3/8- to l/2-in. open graded gravel with k = 30,000 ft/day (Cedegren 1989).

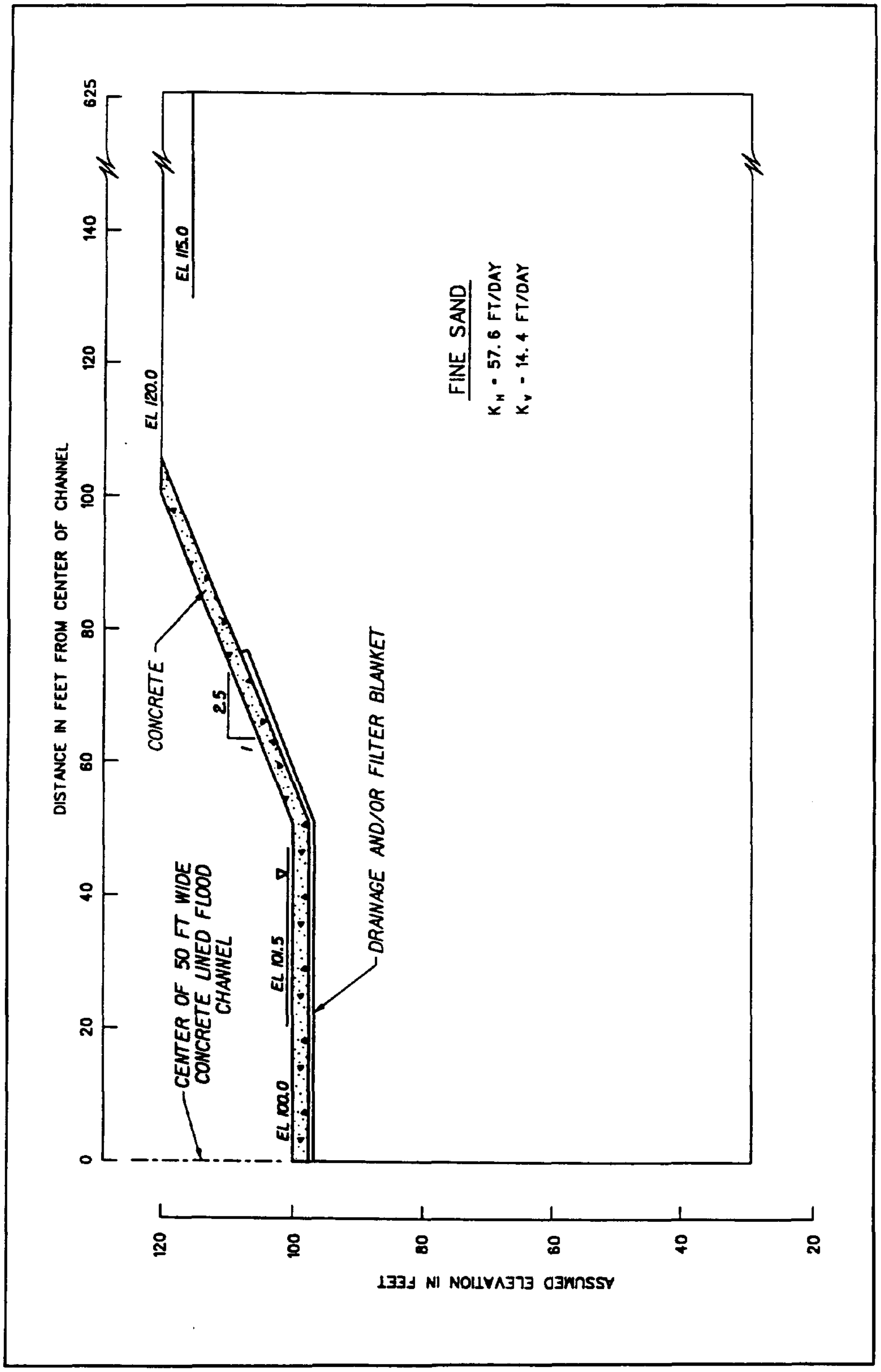

Figure C-10. Example trapezoidal channel and foundation conditions

Table C-3
Data Files for Trapezoidal Channel Seepage Analysis

File TCHNUI							File TCHNUB					
100	1	625	30				100	P	1	1	1	115
110	2	625	97				110	P	2	1	1	115
120	3	625	115				113	P	3	0	1	115
130	4	87.5	115				115	A	1	1	1	
140	5	75	110				120	P	4	1	2	115
150	6	76.1	107.2				130	P	5	1	2	110
155	7	61.8	101.5				135	P	6	1	2	107.2
160	8	50.6	97				140	P	7	0	2	101.5
170	9	0	97				145	A	1	1	1	101.5
180	10	0	30				150	P	8	1	1	101.5
190	11	50.6	30				160	P	9	0	1	101.5
200	12	87.5	30				170	A	1	1	0	
210	13	87.5	97				190	P	10	1	0	
220	14	608	30				210	P	11	1	0	
230	-1						220	P	12	1	0	
240	1	2	F	L	7	1	230	P	13	1	0	
250	2	3	F	L	2	1	240	P	14	0	0	
260	3	4	F	L	30	1						
265	9	8	F	L	5	100						
270	8	7	F	L	1	100						
280	7	6	F	L	1	100						
290	6	5	F	L	0	100						
300	5	4	F	L	1	100						
320	9	10	F	L	7	1						
330	10	11	F	L	5	1						
340	11	8	F	L	7	1						
350	11	12	F	L	5	1						
360	12	13	F	L	7	1						
370	12	14	F	L	29	1						
380	14	1	F	L	0	1						
390	13	4	F	L	2	1						
400	13	8	F	L	5	1						
410	13	2	F	L	30	1						

Table C-4
Results of Trapezoidal Channel Seepage Analysis (Continued)

Plane Flow Problem

Trapezoidal Channel, Lined to Midheight of slope, 1V on 2.5H

0 Number of Nodal Points-----------499
0 Number of Elements----------------451

0 Number of Diff. Materials--------- 1
0 Elevation of Datum----------------- 0.000

Material Properties

MAT	K1	K2
1	0.576E+02	0.144E+02

Node Point Information

Node	BC	X	Y	Flow-Head
	Parts of Listing Omitted			
375	2	61.80	101.50	101.50
387	1	56.20	99.25	101.50
397	1	50.60	97.00	101.50
408	1	42.17	97.00	101.50
419	1	33.73	97.00	101.50
430	1	25.30	97.00	101.50
441	1	16.87	97.00	101.50
451	1	8.43	97.00	101.50
461	1	.00	97.00	101.50

Nodal Flow and Heads

Node		Head	Percentage of Available Head		Flow
Position of Phreatic Surface					
Above	On	Below	X	Y	
	Parts of Listing Omitted				
341			0.1028E+3	905%	
*			80.62	102.84	
353			0.1026E+03	8.2%	
*			75.69	102.60	
364			0.1019E+03	3.3%	
*			62.91	101.94	
375			0.1015E+03	0.0%	-0.2410E+02
		*			
387			0.1015E+03	0.0%	-0.1276E+02
		*			
397			0.1015E+03	0.0%	-0.1756E+02
		*			
408			0.1015E+03	0.0%	-0.9852E+01
		*			
419			0.1015E+03	0.0%	-0.8252E+01
		*			
430			0.1015E+03	0.0%	-0.7364E+01
		*			
441			0.1015E+03	0.0%	-0.6850E+01
		*			

Table C-4 (Concluded)

Nodal Flow and Heads(Continued)

Node		Head	Percentage of Available Head		Flow
Position of Phreatic Surface					
Above	On	Below	X	Y	
451		*	0.1015E+03	.0%	-0.6548E+01
461		*	0.1015E+03	.0%	-0.3264E+01
		Flow (-) =	9.6552E+01	Flows (+) =	9.6169E+01
			Flow (Ave) =	9.6361E+01	

(2) Collector pipe. The collector pipe along the edge of the channel will have the maximum computed flow of 53.9 cu ft/day/ft of length (17.0 cu ft/day + 36.9 cu ft/day). Locating manholes on 500- ft intervals yields an accumulated discharge of 26,950 cu ft/day or 0.31 cu ft/sec. Based on Figure C-11 and using a slope of 0.10 ft/100 ft, a 9-in. diam pipe would be required. The opening sizes in the pipe would need to be 3/8 in. considering equation B-5 and the 3/8- to 1/2-in. open graded gravel to be used for the drain material. For this opening size and drain material, a specified filter gravel would not be required around the collector pipe as was required in the previous example.

(3) Filter layer. A filter layer is needed to protect against migration of the foundation sands into the gravel drainage blanket. A medium to coarse sand will satisfy the filter requirements, as shown in Figure C-12.

(4) Manholes. Manholes to collect and dispose of the upstream drainage would be spaced at about 500-ft intervals along the collector pipe at the toe of the channel slope. Laterals would be required between the collector pipe down the center of the channel and the manholes.

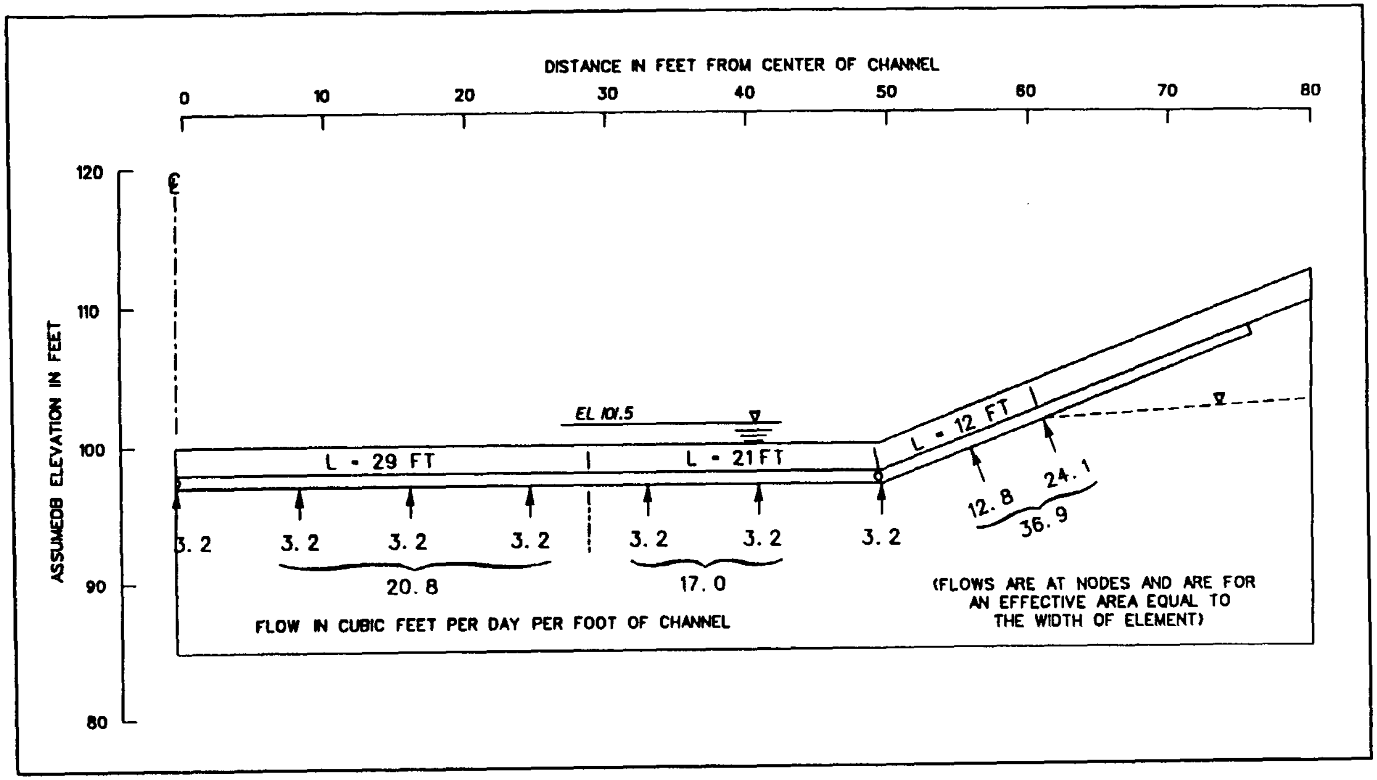

Figure C-11. Flows into drainage blanket from analysis of trapezoidal channel section

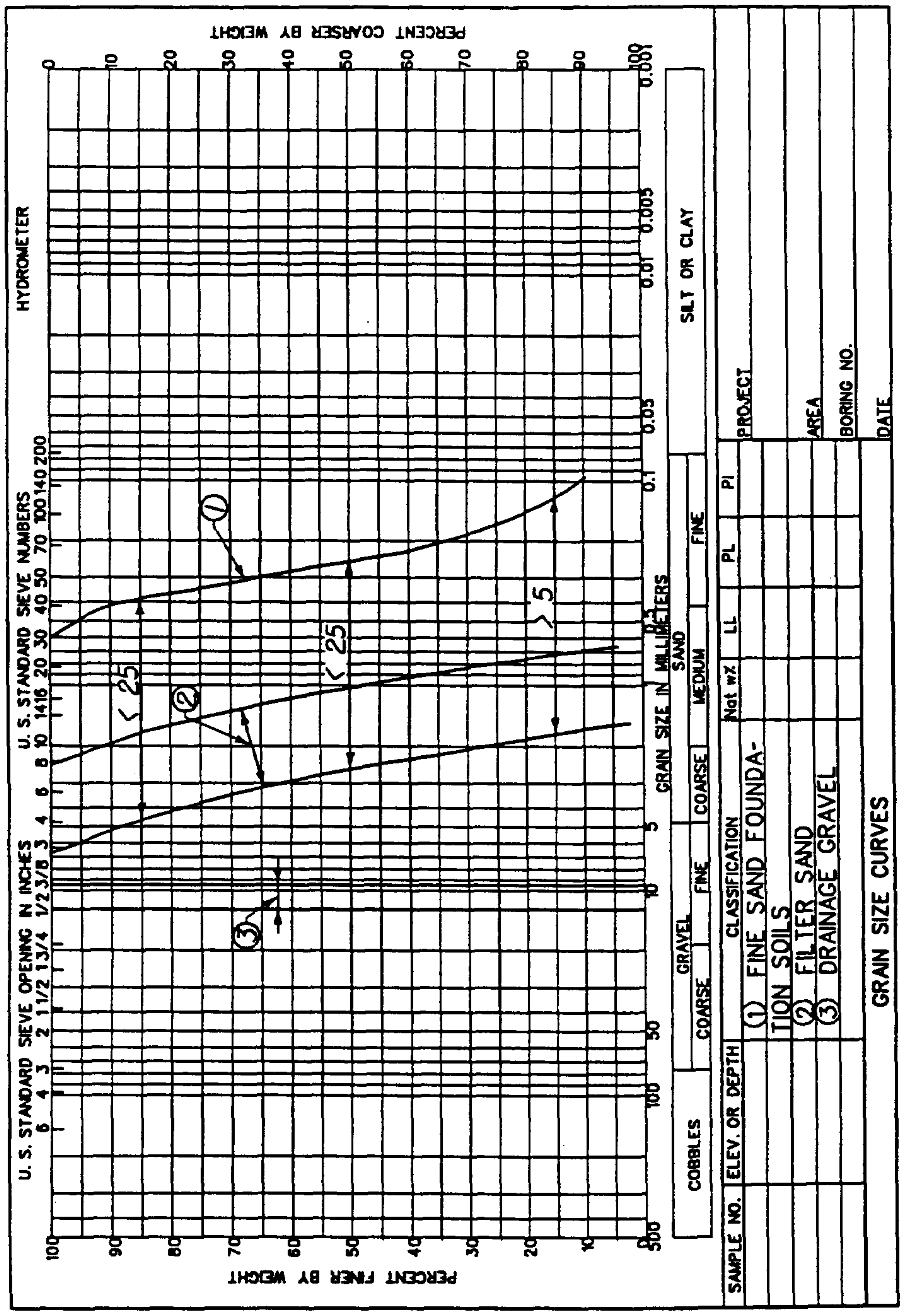

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Figure C-12. Gradation of drainage materials for trapezoidal channel section